Biomechanical analysis of spin bowling action and its variations in relation to accuracy

A Synopsis

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Chapter I

Introduction

Area of Study

Cricket is a sport involving of two opposing teams which are made of 11 players per side in play at any one time. A '12th man' is named within the team, however undertaking a reserve role in the case of player injury. A team is made up of players undertaking four primary roles, these include batsman, bowlers, a wicket-keeper and all-rounders. Match play is classified into the three existing formats of the game. Test cricket is played over a time span of five days, whilst One Day Internationals (ODI's) and Twenty-Twenty (T20) cricket comprising of 50 and 20 overs per side respectively. The foremost difference between these different forms of match play is that in test/first class matches, each team is permitted two opportunities to bat (referred to as an innings).

During match play, one team bats while the other fields, reversing roles at the end of the innings. To be successful in match play, the winning team amasses more runs than their opponent, whilst the objective of the fielding team is to minimise runs scored and 'get the opposition batsman out', a duty which is primarily the responsibility of the bowlers. Once a batsman is given out, the next batsman named within the team enters the field of play. A batsman may lose their wicket in variety of circumstances, these include bowled, caught, run-out, leg-before-wicket (LBW), stumped and the rarest form, hit wicket. The International Cricket Council (ICC), is the highest governing body responsible for organising major international tournaments (such as the ICC Cricket World Cup), sanctioning umpires, enforcing the laws of the game and ensuring that competition is played with the spirit of the game. The compilation and updating for the laws of the game fall under the responsibility of the Marylebone Cricket Club (MCC).

Cricket bowling

Cricket bowling is a fundamental aspect of the game with players broadly categorised as displaying either a spin or fast bowling technique. Bowling is considered a highly complex and multifaceted skill, as this requires the co-ordinated actions of the upper and lower limbs to deliver a 156-163gram cricket ball toward an opposing batsman who is standing approximately 20.12 meters away, awaiting the oncoming delivery. Fundamentally, this skill differs to that of

throwing, since bowlers are constrained to propel the ball via circumduction of the upper limb whilst limiting elbow extension to be less than 15° between upper arm horizontal (UAH) and ball release (BR). Pace or fast bowling is a dynamic activity requiring bowlers to run-up and repeatedly deliver the ball at speeds reaching up to 100mph. Ball release speed is a key contributor to fast bowling success, thereby decreasing the time available to the batsman to decide upon and execute a stroke (Burden & Bartlett, 1990). Conversely, spin bowlers deliver the ball at significantly slower ball release speeds, as they apply various types of spin to the ball with the aim of deceiving the opposing batsman. The application of spin causes the ball to change its trajectory during flight and deviate off the ground (Woolmer & Noakes, 2008).

Statement of the problem

The proposed study is focused on biomechanical factors that allow accurate spin bowling. Further, this study will also investigate how the optimal bowling technique changes with the variations of spin bowling without compromising accuracy.

Objectives of the study

1. To quantify the contribution of variability in ball release parameters—including position, linear velocity, and spin—to the spatial variation in ball landing position during spin bowling.
2. To examine the inter- and intra-bowler variability in key biomechanical determinants at ball release that underpin consistency in landing location among finger and wrist spin bowlers.
3. To analyze biomechanical and ball kinematic changes at ball release when delivering high revolution and variation deliveries compared to stock deliveries in spin bowling.

Hypothesis

1. There is a significant relationship between variability in selected ball release parameters (release position, linear velocity, and spin) and the variability in ball impact location (landing position) for both finger-spin and wrist-spin deliveries.

2. There is a significant relationship between variability in selected kinematic biomechanical variables at ball release and consistency in ball landing location for finger-spin and wrist-spin bowlers.
3. There is a significant relationship between selected kinematic biomechanical variables at ball release and the type of delivery (stock vs. high revolution/variation deliveries) in spin bowling.

Delimitations

1. Bowlers recruited in the study will be injury free so they will not alter their bowling action at the time of data collection.
2. Bowlers selected for studies will be considered elite/sub-elite male standard.
3. Each participant will be either a member of the England men's senior, Lions or U19 cricket team, or a current professional first-class county player.
4. All subjects in the study will bowl with the same make and brand of cricket ball – Dukes Special County 'A' BSI-Grade 1, as used in test and professional county cricket within the United Kingdom.
5. All kinematic studies will be carried out at the same specialist indoor cricket facility permitting testing conditions to be controlled throughout.
6. For studies, bowlers utilizing a bowling action by which the elbow extended greater than 15º elbow extension between upper arm horizontal and ball release will be excluded from the analysis.

Limitations

1. The spin bowling deliveries recorded in this study may not fully reflect deliveries bowled in match conditions due to the laboratory environment. The ecological validity of the testing will be however considered, and testing conditions formed will closely align to match conditions accordingly.

2. The participant sample in studies will reflect the entire population of bowlers that would be considered elite/sub-elite male standard. Consequently, the findings may not apply to bowlers at differing levels of performance or female spin bowling populations.

Definition of terms and abbreviations

1. **Spin rate** – the rate of spin applied to a cricket ball, measured in revolutions per min (rpm).
2. **Finger spin** - a delivery in which the fingers are primarily used to impart spin on the ball.
3. **Wrist spin** - a delivery in which the wrist and fingers are primarily used to impart spin on the ball.
4. **Legside** - the side to which the batsman's legs are closer to whilst in their batting stance i.e. To the left of the batsman. It is also referred to as "onside".
5. **Offside** - the opposing side to legside.
6. **Finger spin/off break** - a delivery bowled by a finger spin bowler where the ball moves in towards the batsman after it has bounced.
7. **Wrist spin/Leg-break** - a delivery where the ball moves away from the batsman after it has bounced.
8. **Doosra** - a variation delivery used by the finger spin bowler, where the ball deviates in the opposite direction to that of the off-spin delivery once it has bounced.
9. **Back foot contact (BFC)** - the instance in which the back foot makes contact with the ground during the delivery stride.
10. **Front foot contact (FFC)** - the instance in which the front foot makes contact with the ground during the delivery stride.
11. **Ball release (BR)** - the instant of ball release was defined as the first image where the distance between the ball marker and the lower arm endpoint was greater than the measured distance from the static calibration ball release trial.
12. **Follow through (FT)** – the finishing position of the bowler once the delivery has been bowled.
13. **Upper arm horizontal (UAH)** - the instant of upper arm horizontal was defined as the first image during the delivery when the vertical location of the elbow joint

centre was higher than the upper arm endpoint.

14. **Illegal bowling action** – utilising a bowling action by which the elbow extends greater than 15º between upper arm horizontal and ball release were excluded from analysis
15. **Drift** - the lateral deviation of the ball during flight.
16. **Drop** - the vertical deviation of the ball during flight.
17. **Magnus force** - generation of a force on a spinning ball or spherical solid immersed in a fluid, liquid or gas, when there is relative motion between the spinning body and the fluid.
18. **Spin axis** – the axis at which the ball spins, perpendicular to the seam of the ball.
19. **Wrong un** – a variation delivery used by the wrist spin bowler, where the ball deviates in the opposite direction to that of the leg-spin delivery once it has bounced.
20. **Slider** - a variation delivery used by the wrist spin bowler, where the ball skids and does not bounce much after pitching.
21. **Topspin** – a variation delivery used by the wrist spin bowler, where the ball maintains its original line and goes straight on towards the batsman! It also allows the bowler to get the ball to dip as well as extract a little bit more bounce from the surface! Basically it bounces upwards more than it bounces sideways!
22. **Flipper** – a variation delivery used by the wrist spin bowler, where the ball ball is released causes it to shoot out of the hand quickly and on a much flatter trajectory. This ball is much more likely to skid low off the pitch due to the backspin that is being applied to the ball!
23. **Arm ball** - a variation delivery used by the finger spin bowler, where the ball does not deviate and holds its line once it hits the pitch.
24. **Accuracy** – An act of bowling where the ball is successfully delivered to hit a defined impact location on the wicket.

Significance and purpose

1. Spin bowling is generally coached using a standard technical framework, but this practice has not been based upon a comparative biomechanical analysis of leg-spin and off-spin bowling.
2. This research addresses a key performance question that is not well understood. With the development and advancement of shorter forms of the game in cricket, the ability to accurately bowl with variations in order to keep the batsmen guessing and prevent runs from being scored has become crucial.
3. The proposed project will bring the next level of understanding that moves the knowledge in the field to the next level.
4. The outcome of this research will provide coaches the key technical parameters of spin bowling to improve accuracy.
5. This will help them design individualised training program and modify training drills to ensure that training protocols match biomechanical demands.

Chapter II

Review of Literature

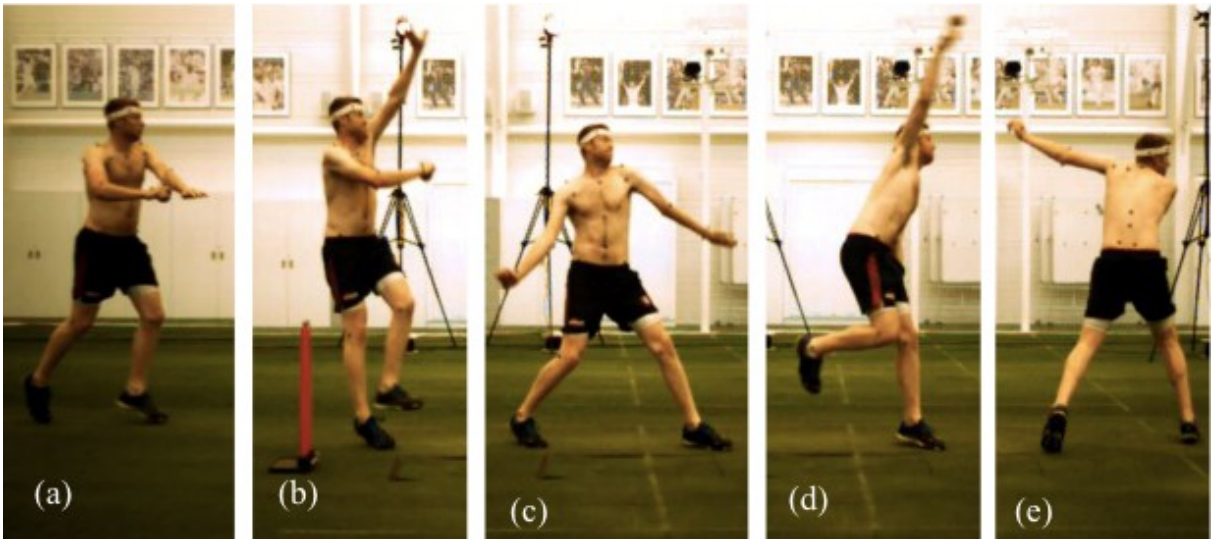
Spin bowlers are sub-classified as finger-spin or wrist-spin. This is determined by the delivery mechanism at the end-point of the body's kinetic chain responsible for imparting revolutions onto the ball, causing fundamental differences in resulting ball kinematics (Beach et al., 2016; 2018; Spratford & Davison, 2010; Spratford et al., 2018; Woolmer & Noakes 2008). A right-arm finger spin bowlers 'standard' delivery, known as the 'offbreak', deviates the ball towards the leg side of a right-handed batsman (i.e. from left to right, from the bowler's perspective), whereas a right-arm wrist-spin bowler deviates the ball to the off side (i.e. from right to left), known as the 'leg-break' (Wilkins, 1991; Woolmer & Noakes, 2008). A spin bowler delivers the ball significantly slower than that of their fast bowling counterparts, whilst aiming to pitch the ball between 2 and 3 m in front of the opposing batting crease (Justham et al., 2010; Woolmer & Noakes, 2008).

The spin bowler's principal task is to deceive the opposing batsman. This is done so via 1) controlling the ball via the lateral (drift) and vertical (drop) deflection in ball flight, combined with 2) deviation from the pitch after bounce (side-spin) (Wilkins, 1991; Woolmer & Noakes, 2008; Spratford et al., 2018), utilising a number of delivery variations; in addition to that of their 'stock' or standard delivery. The stock delivery of the wrist spin bowler is the 'leg break', with three variations commonly employed: (a) the slider, which dips in the air and deviates less than the leg break; (b) the 'googly' or 'wrong'un', which turns towards the right-handed batter's leg side (when bowled from the right-handed bowler); the opposing direction to the leg-break; and (c) the 'flipper', which is a back-spinning delivery that continues on a straight trajectory rather than deviating laterally after contact with the pitch.

The finger spin bowler's delivery variations are determined by fluctuations in ball flight trajectory and release velocity of each delivery. A common variation is the known as the 'arm ball', where the ball deviates in ball flight, away from the right-handed batsman and continuing along its original ball flight path, as opposed to deviating laterally on contact with the pitch. Finally, the 'doosra' (translated as the 'second' or 'other one' in Hindi) is also delivered by the finger spin bowler. Here revolutions are imparted in the opposing direction to that of a stock delivery in an attempt to spin the ball in the opposite direction. Whilst

deemed to be very effective in match play, the doosra is however rarely bowled within the professional game due to it being frequently linked to illegality within the cricket community (Chin et al., 2009). The orientation of the ball at release and the speed and axis of spin during the initial flight of the ball also provides information pertaining to delivery type. This is of particular relevance when facing a spin bowler, whose delivery variations usually manifest themselves as variations in the ball's spin axis relative to the position of the seam.

The vertical launch angle of the ball from the bowler's hand is an important piece of information when considering the ball's pitching length; that is, a steep angle from the horizontal will usually denote a shorter pitching delivery than that of a shallower one. While several modes of delivery exist, irrespective of the type of bowler, the basic aspects of the bowling action are the same and can be broken down into five distinct phases:



From the Fig - Five key instants of the finger spin bowling action: a) the run up, (b) back foot contact (BFC); c) front foot contact (FFC); d) ball release (BR) and e) follow through (FT)

Much of the early research on spin bowling performance attempted to refine methodologies of defining elbow kinematics during the delivery phase with respect to bowling legality (e.g. Ferdinands & Kersting, 2007; Lloyd et al., 2000, Spratford et al., 2018). More recently however, interest has turned toward furthering an understanding of ball kinematics in spin bowlers, with existing research reporting a combination of ball revolutions, ball speed and spin axis angles (e.g. Beach et al., 2014; Chin et al., 2009; Cork et al., 2013; Justham et al., 2010;

2008; Spratford & Davison, 2010; Spratford et al., 2018; Fuss et al., 2011; Fuss et al., 2018), as well as theoretical modelling studies on rotating spherical objects (e.g. Robinson & Robinson, 2016) and computationally complex approaches, such as inverse dynamics analyses used to examine energy transfers in the bowling action and the ball itself.

Chin et al. (2009) compared finger spin bowling kinematics and ball flight mechanics across two groups of differing performance levels: elite (n = 6) and high performance (n=13). Comparisons were drawn across the bowler's standard or stock finger-spin delivery and a bowling variation, known as a "doosra" (where the balls spin axis is the inverse of the stock delivery). Differences in both ball mechanics and kinematics were reported between groups, with the elite group producing both greater rates of spin and ball release speeds. The elite bowlers also displayed significantly greater side-on alignment of the pelvis and thorax at back foot contact (BFC) as well as greater pelvis and shoulder rotation than their high-performance counterparts and greater ranges of forearm rotation and elbow extension between UAH and BR. When compared with the off-break, the doosra was bowled using greater ranges of elbow and wrist extension as well as increased shoulder horizontal rotation. Bowlers also used a significantly longer bowling stride which formed a lower release height. The authors proposed that the increases in joint range at distal segments, namely elbow extension and forearm supination, displayed by the elite bowlers may be associated with the observed increase in ball speed and ball spin rates.

In addition to finger spin, researchers have begun to assess wrist spin bowling technique and quantifying ball kinematics inclusive of; ball release velocity, spin rate, and orientation of the spin axis and seam (e.g. Spratford et al., 2018). Others have sought to identify the fundamental mechanical differences between finger-spin and wrist-spin techniques (e.g. Beach et al., 2016).

In a study comparing both finger (n=23) and wrist (n=20) spin modes, Beach et al. (2016) proposed several variances accounting for the higher spin rates by the wrist-spin bowlers, when compared to finger spin bowlers. These include a significantly larger stride length, lower release height, a smaller rear knee flexion, elbow flexion, higher approach velocities and forearm rotation direction. Given the complexities attributed to a spin bowling technique, the instruction of this skill however has been largely formulated from the collective intuitions of past players. A standardised model of bowling technique has therefore been generally prescribed, with little biomechanics research validating this approach. As the first study to

assess key differences between each modality, the study suggests that finger-spin and wrist-spin are distinct bowling techniques, recommending the development of two different coaching models in spin bowling. Two different action types within each spin bowling technique were reported, Type-1 and Type-2 action types, defined by opposing forearm rotation directions at release, whereby the Type-1 action utilising a supinating forearm, and the Type-2 action with a pronating forearm thus opposing the torque generated on the ball during release.

More recently, Beach et al. (2018) furthered earlier work, investigating the associations between kinematics and spin rate in Type-2 finger-spin and Type-2 wrist-spin bowlers, by examining the magnitude and temporal order of segment angular velocities. Substantial differences in the joint kinematics were observed, which were associated with the ball spin rate between the Type-2 finger-spin and Type-2 wrist-spin techniques using correlation analysis and a generalised linear model. Both bowling groups generally adhered to a proximal-to-distal sequence, whilst the Type-2 finger-spin bowling was associated to a greater extent with the timing of thorax and upper-limb movements. The time of maximum rear hip flexion and maximum arm circumduction velocity were reported to explain the variance in ball spin rate in the Type 2 wrist spin bowlers. Wrist spin bowlers were observed to be using a throwing-type action (Morriss & Bartlett, 1996), which are dependent on creating an increase in the pelvis-shoulder separation maximum velocity. It was also reported that the increases in bowling arm speed were believed to be essential in utilising the supinating technique involved in wrist spin bowling, compared with the pronating technique of finger-spin bowling. The maximum rear hip flexion velocity was the only variable significantly correlated to spin rate in finger spin bowlers, suggesting the rotation of the pelvis is important contributor to spin, whilst for wrist spin bowlers, arm circumduction velocity accounted for variation in ball spin rate, concluding that bowling arm speed is essential to the supinating technique involved in wrist spin bowling techniques (Beach et al., 2018).

Whilst previous research has identified key differences between bowling finger and wrist spin modalities (e.g. Beach et al., 2017), as well as between elite and non-elite group (e.g. Chin et al., 2009: Spratford et al., 2017), studies understanding the mechanisms that underpin the accuracy of spin bowling without compromising spin production are scarce. Some have compared elite and non-elite groups reporting orientations as more side-on at back foot impact, greater elbow extension and larger pelvis and shoulder rotations between back foot contact and ball release (e.g. Chin et al., 2009). Others analysing club level bowlers

suggesting maximum rear hip flexion velocity and rotation of the pelvis as a key contributor to the production of spin (Beach et al., 2018). It has been studied that Off-spin bowlers had a significantly shorter stride length and spin rate, but a greater release height than leg-spinners (Aaron J. Beach et al., 2016*).* It has been understood that finger spin bowlers higher spin rates can be achieved by using a finger spin bowling technique where the pelvis orientation is less side-on which allows a larger pelvis-shoulder separation angle and a shoulder orientation short of side-on at Front Foot Contact (FFC). During the FFC phase, the segments rotated sequentially, starting with the pelvis and finishing with the pronation of the forearm (L. Sanders et al.,2019)

Ball Kinematics

A finger spin bowler delivers the ball using an array of skills to deceive the opposing batsman, which differ significantly to that of their pace bowling counterparts. These include a capability to regulate the deflection of the ball's trajectory during flight, both laterally (known as drift) and vertically (known as drop); ball deviation off the pitch surface post bounce (known as side-spin) and the steepness of ball reflection post bounce (Justham et al., 2010; Justham et al., 2008; Woolmer & Noakes, 2008; Spratford et al., 2017). Whilst it is considered vital to understand the relationship between the ball release conditions and the direction and magnitude of ball displacement during flight (Spratford et al., 2017), previous research dedicated to understanding the mechanisms underpinning this is rare.

The majority of studies in the aerodynamics of balls or spherical objects have included experimental investigations in fast bowling (e.g. Mehta et al., 1983), with more recently researchers applying theoretical modelling methodologies to spin (e.g. Pahinkar & Srinivasan, 2010; Robinson & Robinson, 2013; 2016). In one of the few experimental wind tunnel examinations exploring aerodynamics of ball spin, Sayers & Hill (1999) reported that the force created on the ball was reliant on both the free-stream velocity moving around the boundary layer of the ball and balls rate of spin, known as Magnus force (F_m) or the Magnus 'effect' (named after Heinrich Gustav Magnus, the German physicist who first investigated the phenomenon). In one of the very few studies seeking to understand the effects of Magnus force in spin bowling, Spratford et al. (2017) examined three-dimensional ball kinematics, including ball release velocity, spin rate and orientations of the spin axis and seam between elite and pathway spin bowlers. The magnitude of Magnus force (F_m) applied was reported to be proportional to release speed and spin rate, forming a rationale for why elite spin bowlers

deliver the ball with more drift and at a greater release speeds (Mehta, 1985; Robinson & Robinson, 2013; Watts & Ferrer, 1987). These characteristics of increased drift and steep ball reflection post bounce are widely understood to be significant elements in the finger spin bowler's attempt to deceive an opposing batsman (Woolmer & Noakes, 2008).

Given the paucity of previous studies in this field, particularly within elite groups, there is currently little consensus regarding the effect of these elements of technique on accuracy in elite spin bowlers.

Chapter III

Methodology

Selection of Subjects

Minimum of 10 bowlers for off/finger spin and minimum of 10 bowlers for wrist /leg spin will be selected for the study. Each subject will be either a member of the England men's senior, Lions or U19 cricket team, or a current professional first-class county player.

Selection of variables

Kinematic Variables

- Ball release position (m)
- Ball release linear velocity (rps)
- Ball release angular velocity (m)
- Bowling hand velocity (m/s)
- Bowling wrist velocity (m/s)
- Ball landing location (m)

Research design

Kinematic data will be recorded using an camera (MX13) Vicon Motion Analysis System (OMG Plc, Oxford, UK) operating at 500 Hz, positioned over a capture volume of approximately 7m x 3m x 3m. This frame rate is selected, along with a high camera resolution to certify the accuracy of the data collected, ensuring all markers are tracked effectively within the capture volume given the dynamic action being assessed. Furthermore, to certify the Vicon Motion Analysis System's accuracy was optimised, all cameras were placed to see the capture volume in their field of view.

Fig. 1a) Data collection environment

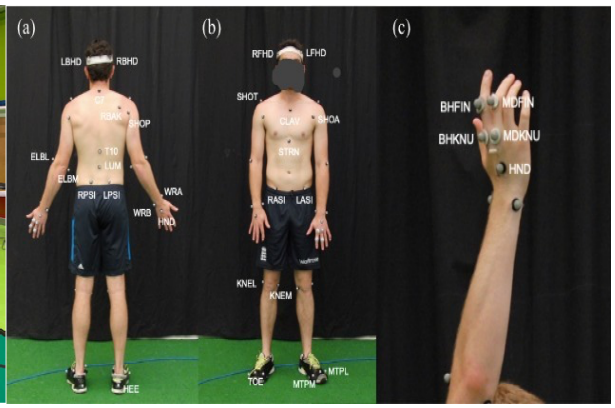


Fig 1b) Whole body marker set

Spin rate data will be recorded using a custom-developed Trackman Doppler radar (TrackMan A/S, Denmark); optimized for the capture of spin bowling trajectories and spin rates.
Kinematic and anthropometric data will be collected at indoor cricket research center, Loughborough University, UK. A specialist indoor cricket facility at Loughborough University, UK will be chosen, as these allowed participants to undergo self-directed warmups and replicate match intensity finger spin bowling deliveries utilizing their desired run up on an artificial full-length pitch.

Administration of test

State-of-the-art biomechanics motion analysis and force plate equipment will be used to accurately record and quantify the techniques used by spin bowlers at the National Cricket Performance Centre at Loughborough University, UK (Figure 1a). Ball impact location/accuracy will be decided by a qualified coach at the time of sample collection. Each participant will bowl 20 deliveries of each delivery type with appropriate rest given between deliveries. All testing procedures will be conducted in accordance with Loughborough University ethical guidelines and informed consent will be obtained in advance from each participant.

Collection of data and Statistical analysis

Subjects body mass will be collected using Seca-Alpha digital scales. Ninety-five anthropometric measurements will be taken enabling subject-specific segmental inertia parameters to be determined for each bowler using a mathematical model (Yeadon, 1990). These measurements will be taken at specific locations on the body by an experienced researcher who will replicate this process for each participant to ensure reliability. These include lengths; widths; depths; and perimeters. This will enable the body to be split into the required 18 segments representing the bowler (head and neck; upper trunk; lower trunk; pelvis; 2 × arm; 2 × lower-arm; 2 × hand; 2 × upper-leg 2 × lower-leg; and 2 × two- segment foot).

Spin bowling kinematic & kinetic performance data and anthropometric data will be collected on a range of elite/first class spin bowlers. All deliveries will be labelled, and key technique variables calculated along with the outcome for each delivery (ball velocity, RPM, impact location on the cricket pitch etc.). The time histories for each key variable will then be analyzed to establish levels of movement variability during the

bowling action for each delivery type and statistical analysis (ANOVA) used to establish how technique changes for each individual when bowling different type of deliveries. Stepwise linear regression will then be used to identify the technique variables that are associated with bowling accurately. Comparison of regression equations will be used to identify and quantify how bowling type and its variations differ from each other.

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